3D visualizations of solid surfaces properties by scanning probe microscopy and spectroscopy technics

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The development of scanning probe microscopy (SPM) as itself and in a combination with optical and spectroscopic technics can give a lot of information on the physical properties of nanostructures:

- Electron state density and work function distribution to use Scanning Tunneling microscopy and spectroscopy;
- The profile of surface structures and its dependence on the pressing pressure;
- Inhomogeneity of the frictional force in the probe-surface system;
- Heterogeneity of adhesion forces;
- Distribution of surface potential (Kelvin-mode);
- Distribution of electrical capacity in the cantilever-surface contact;
- Distribution of thermal conductivity;
- Young's modulus distribution;
- Diagnostics of limits of elastic deformation;
- Distribution of undersurfaces magnetic forces;
- Distribution of piezoelectric characteristics of surface structures;
- The distribution of the optical properties of the surface with a resolution significantly exceeding diffraction limits (near-field optical microscopy);
- Possibility of surface modification.

The application field was increased very wide – from one side micro- and nanoelectronics with extra high-level the metrology requirements and up to material science, biology, ecology with requirements to the side of simplification in operation procedures, possibility of the materials and molecules recognitions.

SPM gives an opportunity to carry out studies of spatial, physical and chemical properties of objects with the typical dimensions of less than a few nanometers. Owing to its multifunctionality, availability and simplicity, Atomic Force Microscope (AFM) has become one of the most prevailing “tools for nanotechnology” nowadays. NTEGRA platform has been designed as the special base for the constantly developing options of SPM that combines them with various other modern research methods: confocal and luminescence microscopy, Raman scattering and Infrared Apertureless Nearfield spectroscopy. Owing to the effect of giant amplification of Raman scattering (TERS – Tip Enhances Raman Scattering) it allows carrying out spectroscopy studies and obtaining images with 10 nm resolution.

New generation of AFM control electronics now allows a real-time cantilever deflection tracking and analyzing. Based on a fast force-distance measurement we developed a new group of non-resonant AFM methods of scanning probe spectroscopy called Hybrid mode. It is the most proposal AFM mode since it summarizes all advantages of amplitude modulation and contact modes allowing simultaneously: free of share force topography measurement with direct tip-sample interaction control, real-time quantitative nanomechanical measurements, conductivity, piezoresponse and electrostatic imaging with conventional scanning speed. Hybrid mode is also very helpful for liquid measurements as it utilizes the issue with cantilever eigenfrequency detection.

Progress in micromechanics manufacturing resulted in significant increase of the cantilever yield rate (to practically 100%) with repeatability of resonant characteristics at 10% level, thus preconditioning implementation of the concept of multi-probe cartridges for AFM. A cartridge is a multi-probe contour-type sensor with 38 cantilevers. The cantilevers can be either of the same type or "colored" with predefined coverings and rigidities. Depending on AFM system type the cartridge rotation to select working cantilever can be manual or software-controlled and takes a few seconds. A whole cartridge can be exchanged manually through a simple procedure without the risk to damage cantilevers. The cartridges operate in dedicated measuring heads, which are designed for integration in the latest Company instruments (Titanium, NEXT, SOLVER-NANO, VEGA-SPM).

For fully software-controlled AFMs Titanium and NEXT the cantilever setup procedure was motorized and automated including: precise cartridge rotation to the user-selected cantilever, optical beam deflection (OBD) system adjustment, lock-in amplifier tuning and sample positioning. This approaches us to the concept of ease-of-use AFM where routine system adjustment before scanning is proceeded automatically in a few tens of seconds. Ease-of-use is not the only feature of automated multi-probe cartridge. One of the most demanding applications of modern AFM is routine and repeatable atomic and molecular resolution. This requires extra-low tip-sample thermal drift assumed us lower than 1 Å/min. Development of thermally stabilized cabinet with 0.01°C temperature control accuracy and drift-minimized mechanical design of Titanium AFM helped us to achieve mentioned drift level and repeatable atomic/molecular resolution imaging. But conventional cantilever exchange procedure requires opening the cabinet and manipulating with AFM therefore destabilizing the temperature conditions. So the concept of automated multi-probe cartridge together with active thermal stabilization and drift-minimized mechanical design can be a perfect tool for routine high-resolution AFM imaging.

AFM is a candidate to solve some of “Metrology Difficult Challenges” proposed by The International Technology Roadmap for Semiconductors like: “Structural and elemental analysis at device dimensions and measurements for beyond CMOS”, “Nondestructive, production worthy wafer and mask-level microscopy for critical dimension measurement for 3D structures, overlay, defect detection, and analysis”. A rapid development of polymer and single-molecular electronics also requires AFM to measure and control the topography, nanomechanical, conductivity, temperature and other properties at the nanoscale. To summarize, future electronics development and manufacturing can be a wide field for AFM application, especially for large-sample AFMs. But the biggest drawback of AFM technology to overcome is low throughput.

Throughput of AFM is limited by: system adjustment time before scanning (OBD system and lock-in adjustment, area of interest searching time etc.), scanning parameters adjustment time, scanning speed and amount of data gathered after one scanning session. So to develop the next-generation AFM all these limits should be overcome.

To minimize system adjustment and scanning parameters tuning time we develop and improve new software algorithms allowing fully automated topography imaging. New high-speed control electronics together with Hybrid mode allow more data points and different properties to be recorded per one scanning session. We also develop new AFM-scanner control algorithms to increase a topography imaging speed noticeably. These developments implemented to the fully motorized large-sample AFM is a promising tool for nanotechnology industry. To use AFM-cluster technology in the portable SPM, such as Solver-NANO can open the road for using of this unit right on the Space Stations for material quality control in Space and Space Station conditions.

Development of modes for scanning spectroscopy combined with SPM in the instruments NTEGRA-SPECTRA-II provides new options of confocal laser luminescence spectroscopy and Raman spectroscopy as well as higher reliability of detection for TERS and high-resolution scanning probe-optical microscopy and spectroscopy. Probes with diamond nanocrystals containing N-V defects are capable to detect magnetic states as microscopic as single spins and so they are promising for studies of surface catalytic activity and for detection of free radicals, including applications in biology and medicine.

Apertureless scanning nearfield optical microscope (ASNOM) probe induce lite scattering give the possibility to investigate infrared as chemical nature of surface functional gropes and to measure the doped impurity implantations in microelectronic structures that it impossible to observed in electron microscopy.